MEMORANDUM REPORT ARBRL-MR-03109

AN IMPROVED EXPEDIENT PROPELLANT CHARGE TO OBTAIN HIGH MUZZLE VELOCITY IN A 20-MM EXPERIMENTAL GUN

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

REPORT DOCUMENTATION PAGE

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DU long rod penetrator
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (mph)

The Ballistic Research Laboratory funded the TSD-SCTB-SCDTS, ARRADCOM to conduct terminal ballistic test at velocities of 1520 m/s (5000 ft/s). The gun system, a 20-mm smooth bore/30-mm breech and IMR 4996 propellant, launched tungsten alloy penetrators successfully. However, the depleted uranium rods experienced severe deformation and fracture during launch.

This report describes a suitable propelling charge that can be used to successfully launch DU long rod penetrators at 1520 m/s.

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1. INTRODUCTION

1.1 Background

The use of in-house Terminal Ballistic Range facilities for testing depleted uranium (DU) penetrators has been curtailed because of necessary clean-up and range modifications to comply with Nuclear Regulatory Commission requirements. Meanwhile targets designed and fabricated by Aeronautical Research Associates of Princeton (ARAP) were ready to be tested. The Ballistic Research Laboratory was tasked with the responsibility to obtain the terminal ballistic data.

The Test and Instrumentation Division, Technical Support Directorate, ARRADCOM, had operative at Dover, NJ, a facility for testing DU, and had demonstrated the capability of launching 65-gram tungsten alloy long rod penetrators at muzzle velocities of 1524 m/s (5000 ft/s).

The Ballistic Research Laboratory funded the Dover test site to conduct the necessary firings to provide terminal ballistic data from DU long rod penetrators attacking the ARAP targets at velocities to 1524 m/s.

However, unlike tungsten alloy penetrators, the DU rods experienced severe plastic deformation during launch.

1.2 Initial Experiment

1.2.1 Projectile. The projectile was fabricated from DU alloyed with 0.75 weight % of titanium. The yield strength of the penetrator was approximately 0.776×10^9 Pa (112,500 psi). The hardness of the penetrator was Rockwell "C" 40. The DU billets were purchased from Dow Chemical Company, Rocky Flats Division, Golden, CO.

The projectiles were fabricated from 3.56-cm diameter rods that were extruded from 10.16-cm billets. The billets were alpha phase extruded at 600^0C. The 3.56-cm diameter rods were then gamma phase solution treated at 800^0C in a static vacuum. After directional quenching, the bars were aged for 16 hours at 350^0C in molten lead. The rods were cut longitudinally into quadrants, and the penetrators were machined from these quadrants. The penetrators were 0.762 cm in diameter, 7.62 cm in length, and 65 grams in weight. The projectiles were fabricated at Battelle Pacific Northwest Laboratories, Richland, Washington.

1.2.2 Launcher. The launcher consisted of a 4.27-m (14-ft), 20-mm smooth bore barrel, and a 30-mm breech, having a length of 18. cm (7 in.). Straight wall cases of the 30-mm Frankford Arsenal type 15-E1 variety were used. The rounds were separately loaded. Electric Primers, M52A3B1, were used.

1.2.3. Sabot. The sabot design consisted of a molded, rag filled phenolic fiber with a square milled hole, followed by a thin, 0.2 cm (.08 in.) steel disc. An aluminum "hat" followed the steel disc which was followed by a plastic polypropelex obturator. Figure 1 shows the steel disc and schematic of the sabot assembly. The total weight of the sabot assembly was 35 grams.

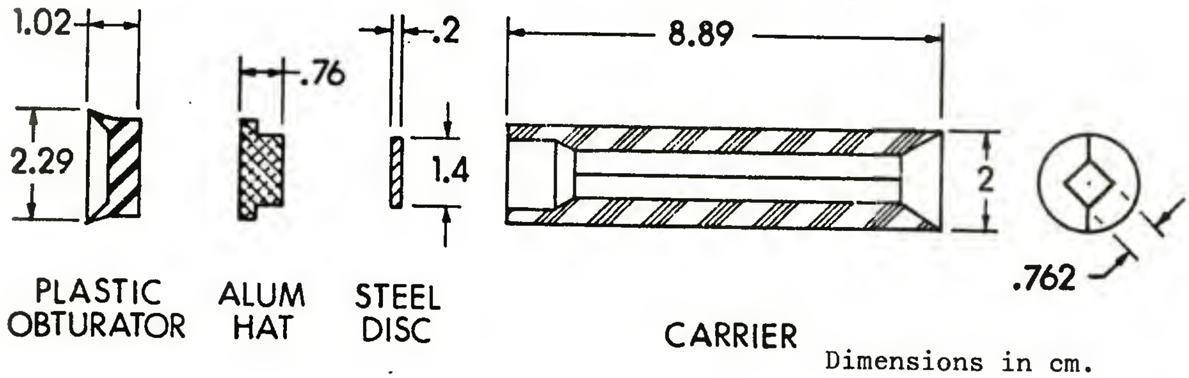

Figure 1. Sabot Assembly

1.2.4. Instrumentation. X-ray instrumentation[1] was used to record the event. The x-ray film images were used to determine the striking velocity and striking yaw.

1.2.5. Firings with IMR 4996 Propellant. The use of IMR 4996 propellant caused rapid acceleration of the launch package resulting in a setback force that exceeded the yield strength of the penetrator material. These conditions caused deformation and fracture of the penetrator material.

[1] *C. Grabarek and L. Herr, "X-Ray Multi-Flash System for Measurement of Projectile Performance at the Target". Ballistic Research Laboratories Technical Note No. 1634, September 1966 (AD No. 807619).*

2. OBJECTIVE

The objective was to find a launcher/sabot/propellant combination for launching the specified DU projectiles at the desired velocity, 1524 m/s, without permanent projectile deformation due to setback forces.

3. APPROACH

The following approach was taken to achieve this objective:

1. Modify sabot design but use the same propellant and launcher.

If (1) proves unsuccessful, request the Interior Ballistics Division (IBD) of BRL to assist in providing a suitable propelling charge.

2. Change propelling charge but use same chamber.

3. Change propelling charge and increase size of chamber.

4. RESULTS

4.1. Sabot Modification

The sabot was modified to provide "cushioning" and to prevent the penetrator from penetrating or perforating the steel pusher disc during setback. The modification included the following:

a. Increased the number of steel pusher plates to two.

b. Increased the length of the aluminum "hat" from 0.76 cm to 1.86 cm.

c. Increased the length of plastic obturator from 1.02 cm to 1.84 cm.

Even with these sabot modifications, permanent deformation of the penetrator owing to setback forces still occurred. The rapid acceleration of the launch package produced by the propellant IMR 4996 was more than could be handled by state-of-the-art sabot modifications; and, consequently, a search for a different propelling charge was in order.

4.2 Propellant Charge

4.2.1. Measuring Pressure During Launch. A copper crusher gage was used to measure the maximum pressure during launch. The copper crusher gage was placed midway into the cartridge. The distance between the gage and the base of the sabot was 24.8 cm. Table 2 lists the chamber pressures and resulting muzzle velocities. Preliminary tests indicate that to achieve a muzzle velocity of 1524 m/s, a chamber pressure of about 454.4 MPa (66,000 psi) is required (test number 5). Maximum pressures may be up to 10% higher than those calculated from the deformation of the copper gages. A 5% increase in pressure would result in chamber pressure of about 482.7 MPa (70,000 psi). Using the estimated value, the pressure on the base of the penetrator, due to setback forces, was estimated to be 1358 MPa, which obviously exceeds the yield strength of DU-3/4 Ti, which is 776. MPa. It was decided to proceed to Step 2 of the approach, namely, search for an improved propelling charge.

4.2.2. Interior Ballistic Computer Simulations and Exploratory Firings. The procedure to obtain the proper propellant charge was handicapped by lack of continuous pressure-time history measurements of the interior ballistic trajectory, such as would be obtained from piezoelectric or resistive type gages and recording equipment. Instead, copper crusher gages were used throughout, and the maximum pressures these devices recorded were coupled with the muzzle velocities to serve as input to the BRL Small Arms Interior Ballistic computer program (SAIB)[2]. The output from this program simulated the interior ballistic trajectories (IBT).

The first simulation computed was that using the IMR 4996 propellant. The maximum gage pressure attained during the simulated high velocity launch was 524 MPa (76,000 psi). The simulation took into account the deterrent coating on the surface of the IMR 4996 propellant. Plots of the simulation are shown in Figures 2, 3, and 4: pressure vs time, pressure vs travel, and velocity-travel-acceleration vs time. The simulation indicated that the peak acceleration exceeded 1.04×10^6 m/s^2, and the average acceleration with time was about 0.37×10^6 m/s^2.

The obvious solution to the problem was to substitute for the IMR 4996 a different propellant which would reduce the peak acceleration, but still deliver the desired velocity. The reduction in the peak acceleration would produce a lower setback force which should not exceed the yield strength of the penetrator. Because the test-firing

[2] *T. R. Trafton, "An Improved Interior Ballistic Model for Small Arms using Deterred Propellants", Ballistic Research Laboratory Report No. 1624, November 1972 (AD 907962L).*

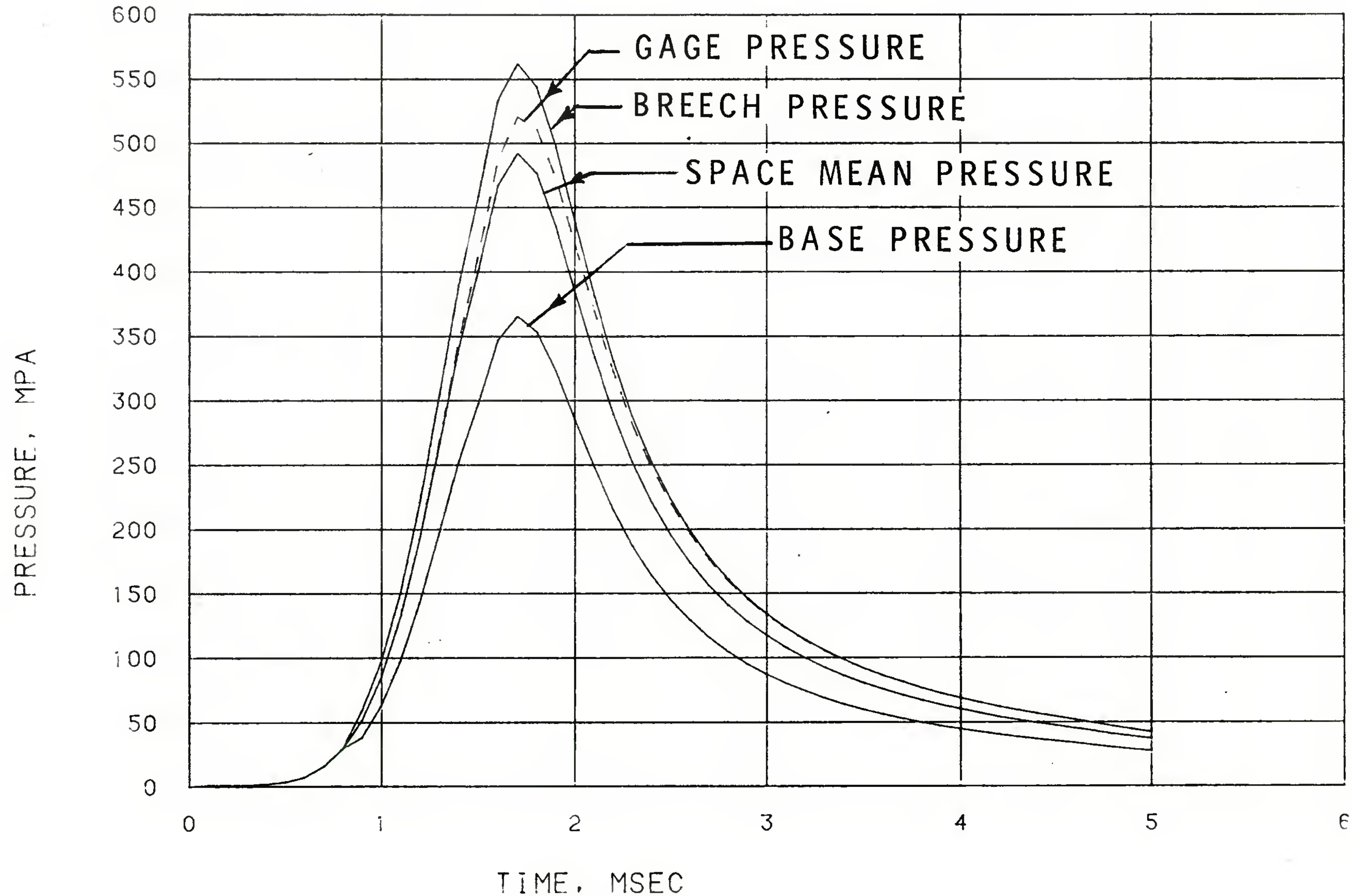

Figure 2. Pressure vs Time - IMR 4996

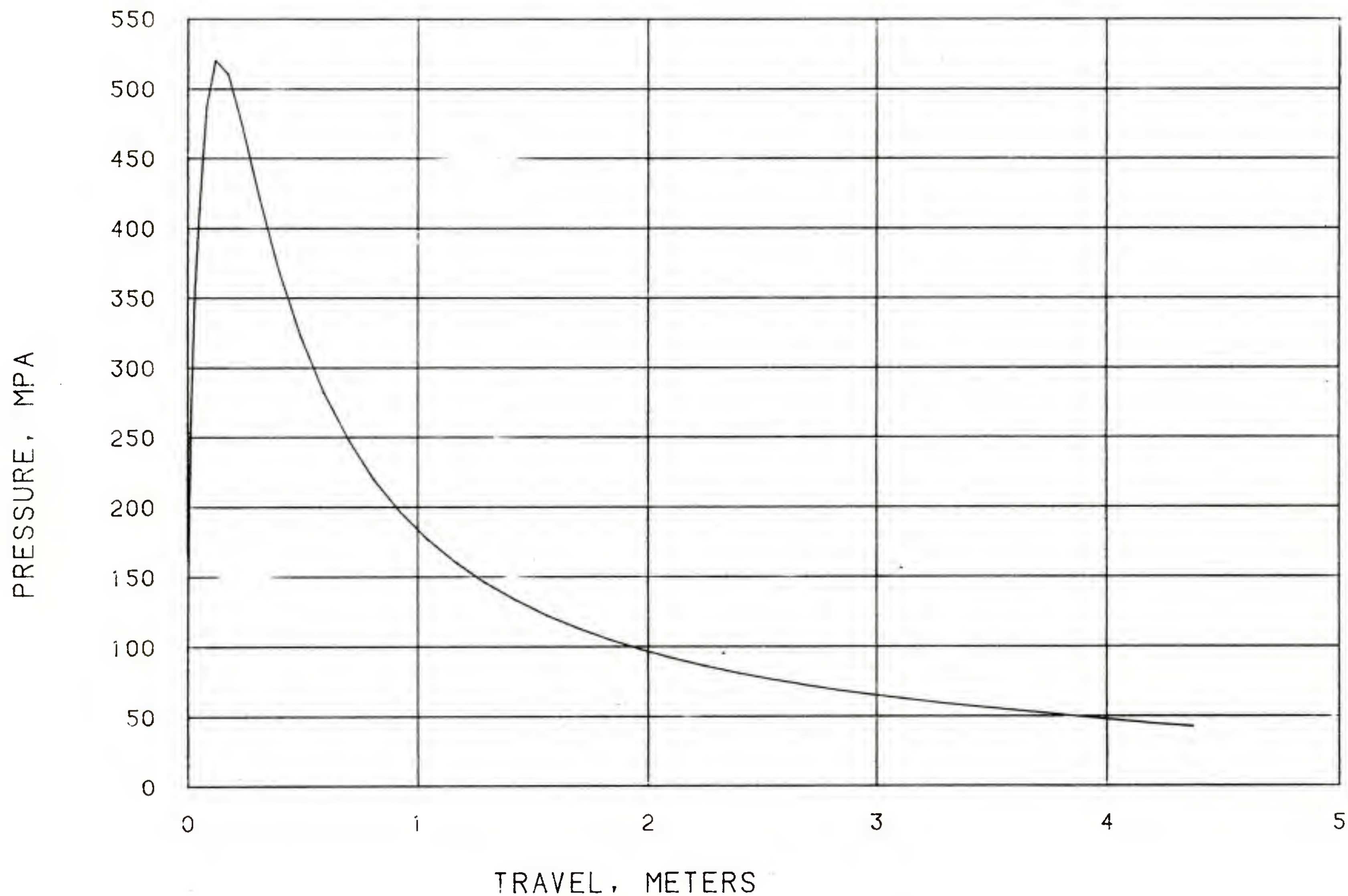

Figure 3. Pressure vs Travel - IMR 4996

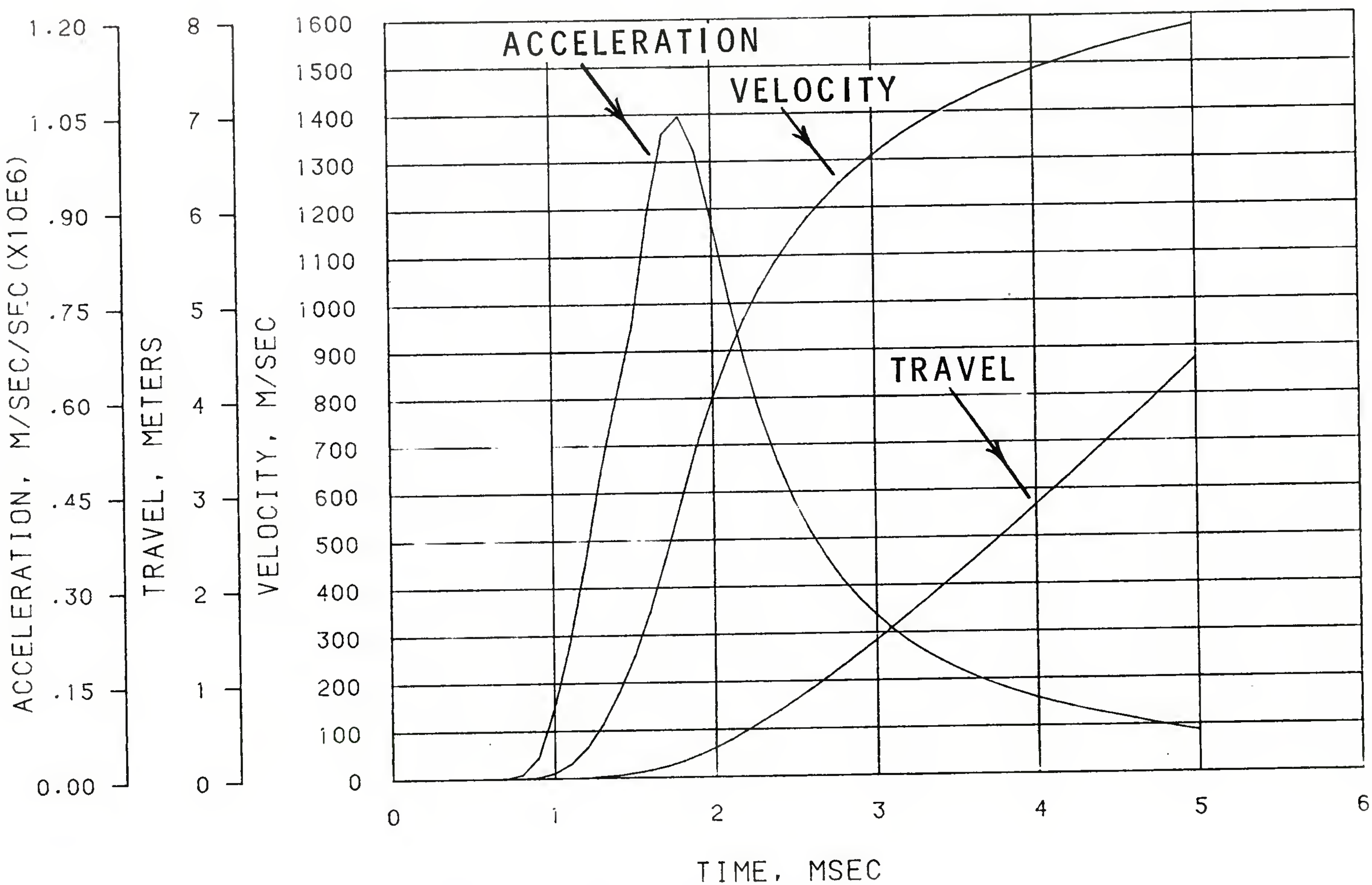

Figure 4. Velocity-Travel-Acceleration vs Time - IMR 4996

program was already in progress with the test equipment in place, the substitute propellant had to be readily available for immediate use. A Hercules propellant, HC-25-FS, had already been tried as a substitute, and had yielded similarly unsatisfactory results. Examination of a list of IMR-type propellants disclosed two possible candidate propellants, each with a lower relative quickness than IMR 4996. These are compared with IMR 4996 and the reference propellant IMR 4350 as follows:

Propellant	Relative Quickness
IMR 4350 (reference)	100
IMR 4996	51
IMR 8446M	45
IMR 8486M	44

Attempts to locate a quickly available source for these two propellants were unproductive. Therefore, although these two propellants appeared to be promising, further effort for their immediate application was discontinued.

An alternate approach to the choice of a substitute propellant was to examine large caliber propellant compositions and depend on the granulation to deliver the desired performance. Two alternate compositions, M-1 and M-30, were evaluated with the IMR 4996 for their thermochemical characteristics as shown in Table 1. Three readily available lots of the M-1 composition and one lot of M-30 composition were simulated as charges substituting for the IMR 4996 to obtain their predicted interior ballistic performances. Propellant description sheets for these lots were given in Figure 5, 6, 7, and 8. The simulations for the M-1 composition lots gave discouraging results.

Table 1. Selected Thermochemical Characteristics (Loading Density = 0.2)

Composition Type	Flame Temp (K)	Specific Force (joules/gram)	Ratio of Specific Heats (γ)	Pressure* (MPA)
IMR 4996	2843	994.	1.2452	250.8
M-1	2448	920.	1.2669	236.4
M-30	3007	1075.	1.2414	272.3

*Pressure obtained in a closed bomb determination of a loading density of 0.2.

U.S. Army Lot No.: RAD-E-12-72 of 19 73 Composition No. M1, MP for 155mm, XM164

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 122,194 pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. MIL-STD-652B and RAAPPD 2010

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
B-14,431Y, 14,435Y, 14,436Y, 14,453Y, 14,454Y, and 14,455Y	Maximum 13.17 %	Mins	Mins
	Minimum 13.12 %	Mins	Mins
	Average 13.15 %	45+ Mins	30+ Mins
Y designates wood sulfite cellulose.			Explosion Mins

MANUFACTURE OF PROPELLANT

0.62 Pounds Solvent per Pound XX/ Dry Weight Ingredients Consisting of 35 Pounds Alcohol and 65 Pounds Ether per 100 Pounds Solvent

Percentage Remix to Whole 10

Temperatures °C From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
	35	Load Solvent Recovery Tank		
35	55	Increase Solvent Recovery Temperature		6
	55	Hold Solvent Recovery Temperature		30
	65	Water Dry Cycle		24 to 40
	55	Air Dry Cycle		3 to 4

TESTS OF FINISHED PROPELLANT

Propellant Composition * Constituent	Percent Formula	Percent Tolerance	Percent Measured	Stability and Physical Tests	Formula	Actual
Nitrocellulose	85.00	±2.00	84.95	Heat Test: SP, 134.5°C	No CC 40'	60'
Dinitrotoluene	10.00	±2.00	10.27	No Explosion	5 Hrs. Min.	5 Hrs.
Dibutylphthalate	5.00	±1.00	4.78	Form of Propellant	Grain Type I	
Total	100.00		100.00	No. of Perforations		7
Diphenylamine (Added)	1.00	+0.20, -0.10	1.04			
Potassium Sulfate (Added)	1.00	±0.30	1.08	Compressibility,	30 Min.	47
Total Volatiles			1.63	percent		
Moisture	0.60	±0.20	0.65			
Residual Solvents	1.05	Max.	0.98			

CLOSED BOMB

Test	Lot Number	Temp °F	Relative Quickness, %	Relative Force, %
	RAD-E-12-72	+90	101	100
Standard	RAD-E-4-72	+90	100	100

Remarks: FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 200CC CLOSED BOMB.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec	Actual
Length (L)		0.330	0.3209	6.25 Max.	1.16
Diameter (D)		0.207	0.1428	6.25 Max.	2.39
Perf Dia (d)		0.021	0.0149		
WEB:					
INNER		0.0385	0.0235		
OUTER		0.0335	0.0254		
AVERAGE		0.036	0.0245		
Web Difference/Std Dev. in % of Web Average	15 Max.		7.4		
L/D	2.10 to 2.50		2.25		
D/d	5.0 to 15		9.6		

DATES	
Packed	1/26/73
Sampled	1/26/73
Test Finished	2/6/73
Offered	2/14/73
Description Sheets Forwarded	2/22/73

Type of Packing Container: Fiber Drums per MIL-STD-652B.

Remarks: *Computed on total volatiles, diphenylamine, and potassium sulfate free basis.

This lot meets all requirements of the applicable specification.

Contractor's Representative	Government Quality Assurance Representative
P. W. STEELE R.W. Steele 2-14-73	JAMES E. BLAND James E. Bland

Figure 5. Propellant Description Sheet - RAD-E-12-72

AMC PROPELLANT DESCRIPTION SHEET
(AMCR 715-509)

XXXXX LOT NO. CIL-67338 OF ____ COMPOSITION NO. M1 .034 MP (SULF. FOR M4A2 Propelling Charge for 155 MM Howitzer Cannon V-3 30623)

MANUFACTURED AT: Canadian Industries Limited, Valleyfield, P.Q., Canada PACKED WEIGHT 441,000 lbs

CONTRACT NO. DAAA-09-69 C-0313 DATE Dec. 27, 1968 SPECIFICATION NO. MIL-STD-652A (MU) REVISION OF 15 Sept. 1965

NITROCELLULOSE

ACCEPTED BLENDS (Nos.) C(1) 186 to 221 incl. 223 to 233 incl. 235 to 247 inclusive

NITROGEN CONTENT		R.L. STARCH TEST (65.5° C)		STABILITY TEST (135° C)	
MAXIMUM	% 13.19	MAXIMUM	-- MINS.	MAXIMUM	-- MINS.
MINIMUM	% 13.10	MINIMUM	36+ MINS.	MINIMUM	30 MINS.
AVERAGE	% 13.14	AVERAGE	MINS.	AVERAGE	-- MINS.
				EXPLOSION	MINS.

MANUFACTURER OF PROPELLANT

TOTAL WEIGHT OF SOLVENT PER POUND NC 0.65 CONSISTING OF 35 POUNDS ACOHOL AND 65 POUNDS ETHER PER 100 POUND SOLVENT. PERCENTAGE OF REMIX TO WHOLE ____

TEMPS. °C. FROM	TO	PROCESS-SOLVENT RECOVERY AND DRYING	TIME DAYS	HOURS
25	65	Solvent Recovery		80 Hrs.&Cool
65	65	Water Dry		108 Hours
55	55	C.C.		10 Hours

TESTS OF FINISHED PROPELLANT

COMPOSITION CONSTITUENT	Formula	MFR.	INSPR.	STABILITY AND PHYSICAL TESTS	MFR.	INSPR.
Nitrocellulose	85.00 ± 2.00	84.40		135° C HEAT TEST, S. P.	55	50
Dinitrotoluene	10.00 ± 2.00	9.91		(EXPLOSION	5+	5+
Dibutylphthalate	5.00 ± 1.00	5.69		FORM OF GRAIN	M.P.	
Diphenylamine (Added)	1.00 ± 0.10	0.98		NO. OF PERFORATIONS	7	
Pot. Sulfate (Added)	1.00 ± 0.30	1.04		NO. OF GRAINS PER POUND	1576	
Residual Solvent	1.26 (Max.)	0.37		BURNING SURFACE PER POUND (sq. inches)	753	
TOTAL VOLATION	2.06 (Max.)	1.07		GRAV. DENSITY, OR POUNDS PER CU. FT.	--	
MOISTURE	0.60 ± 0.20	0.70		SPECIFIC GRAVITY	--	
ASH	N/A	--		HYGROSCOPICITY (1.35 Max.)	1.13	
				COMPRESSION TEST (30% Min.)	32.8	

GRAIN DIMENSIONS	DIE (Inches)	FINISHED GRAIN (Inches) MANUFACTURER	INSPECTOR	STD. DEVIATION IN PER CENT OF MEAN DIMENSIONS MANUFACTURER	INSPECTOR
LENGTH (L)	0.480	0.4341		2.05	
DIAMETER (D)	0.264	0.1866		1.80	
DIAMETER OF PERFORATIONS (d)	0.025	0.0176			
WEB INNER	0.0490	0.0338			
WEB OUTER	0.0455	0.0340			
WEB AVERAGE		0.0339			
WEB CALCULATED		--			
DIFFERENCE BETWEEN INNER AND OUTER		--			
WEB IN PER CENT OF WEB AVERAGE		+0.59			
L:D (Y)		2.30			
D:d (X)		10.72			

DATE PACKED May 21, 1969 DATE OFFERED May 23, 1969 DATE SAMPLED May 23, 1969

DATE TEST FINISHED June 2, 1969 DATE DESCRIPTION SHEETS FORWARDED June 2, 1969

TYPE OF PACKING BOX Fibre drums ICC Specification 21C

REMARKS: This lot meets the chemical and physical requirements of Specification MIL-STD-652A (MU) dated 15 September 1965. Accepted subject to gun proof.

SUPERINTENDENT D.M. MacLean (D.M. MacLean) QU REP G. Toupin (G. Toupin) CHEMIST (G.F. Mallette)

Figure 6. Propellant Description Sheet - CIL-67338

U.S. ARMY LOT NO. BAJ-67782 OF Cannon Propellant Charge M-3A1(GB) for use in 155 mm, ~~M3A1~~ Howitzer Cannon (V3-30619) COMPOSITION NO. M-1 FOR 155 mm Howitzer

MANUFACTURED AT: Badger Army Ammunition Plant PACKED WEIGHT 300,090 lbs

CONTRACT NO. DAAA09-69-C-0014 DATE 1 Sept. 1968 SPECIFICATION NO. MIL-P-60416 (MU) REVISION OF EOPA 47035-S

ACCEPTED BLENDS (No.) (PULP)B10,301, 310 NITROCELLULOSE C10,639, 640, 641-42A&B, 643-44A&B, 645-649, 652-657, 659, 660, 663, 664, 666-670, 672, 674, 676

NITROGEN CONTENT		65.5°C KI TEST		STABILITY TEST 134.5°C.	
MAXIMUM	% 13.18	MAXIMUM	45 MINS.	MAXIMUM	35 MINS.
MINIMUM	% 13.12	MINIMUM	45 MINS	MINIMUM	30 MINS.
AVERAGE	% 13.14	AVERAGE	45 MINS	AVERAGE	30 MINS.
				EXPLOSION	-- MINS

MANUFACTURER OF PROPELLANT

TOTAL WEIGHT OF SOLVENT PER POUND NC 0.55 - 0.65 CONSISTING OF 36 POUNDS ACOHOL AND 64 POUNDS ETHER PER 100 POUND SOLVENT. PERCENTAGE OF REMIX TO WHOLE

TEMPS. °C. FROM	TO	PROCESS-SOLVENT RECOVERY AND DRYING	TIME DAYS	HOURS
40	55	Solvent Recovery	1	8
	60	Water Dry	1/2 - 1	
	55	Air Dry		0-5

TESTS OF FINISHED PROPELLANT

CONSTITUENT *	FORMULA	~~XXX~~	INSPR.	STABILITY AND PHYSICAL TESTS		MFR.	INSPR.
Nitrocellulose	85.00	±2.00	84.86	HEAT TEST / 120°C ☐ 134.5°C ☒	Minutes (Min.)	40	50
Dinitrotoluene	10.00	±2.00	10.12	No EXPLOSION	Hours(Min.)	5	5+
ibutylphthalate	5.00	±1.00	5.02	FORM OF GRAIN	TYPE II	Cyl.	Cyl.
TOTAL			100.00	NO. OF PERFORATIONS		1	1
Diphenylamine (Added)	1.00	±0.10	1.00	NO. OF GRAINS PER POUND			
Potassium Sulfate (Added)	1.00	±0.30	0.94	BURNING SURFACE PER POUND (sq. inches)			
TOTAL VOLATILES				GRAV. DENSITY, OR POUNDS PER CU. FT.			
MOISTURE	0.60	±0.20	0.68	SPECIFIC GRAVITY			
ASH				HYGROSCOPICITY			
Residual Solvent	0.88	Max.	0.59	COMPRESSION TEST			

GRAIN DIMENSIONS	DIE (Inches)	FINISHED GRAIN (Inches) SPECS. ~~XXXXXXXXXXXX~~	INSPECTOR	MEAN VARIATION IN PER CENT OF MEAN DIMENSIONS SPECS. ~~XXXXXXXXXXX~~	INSPECTOR
LENGTH (L)	0.2220		0.2226	6.25	3.65
DIAMETER (D)	0.0700		0.0518	6.25	5.86
DIAMETER OF PERFORATIONS (d)	0.0300		0.0169		
WEB INNER					
WEB OUTER					
WEB AVERAGE	0.0200		0.0175		
~~CALCULATED~~ Web Standard Deviation					
WEB IN PER CENT OF WEB AVERAGE		20% Max.	12.12		
L:D (Y)		3.0 - 6.0	4.30		
D:d (X)		Approx. 3	3.07		

DATE PACKED 7/1/70 DATE OFFERED DATE SAMPLED 7/1/70

DATE TEST FINISHED 7/8/70 DATE DESCRIPTION SHEETS FORWARDED 7/8/70

TYPE OF PACKING BOX Fiber Drums

REMARKS: *Computed on T.V., Diphenylamine and Potassium Sulfate free basis.
This Lot meets all the chemical and physical requirements of the applicable specifications.

FSN

LABORATORY SUPERINTENDENT	TECHNICAL DIRECTOR (ACTING)	CHIEF, U.S. CHEMIST
R. J. Thiede / P. Crest	B. Drumbach	Ronald E. Wahlgren

SMU FORM 1047 MAR 1968 REPLACES AMC FORM 1047, WHICH IS TO BE USED UNTIL SUPPLIES ARE EXHAUSTED

Figure 7. Propellant Description Sheet - BAJ-67782

PROPELLANT DESCRIPTION SHEET

U S Army Lot No. RAD-69315 of 19 75 Composition No. M30, f/Ctg., TPDS-T, M724E1 f/105MM,M68

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 310,545 Pounds

Contract No DAAA09-71-C-0329 Date 6-30-71 Specification No MIL-P-48154

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

A-35,475; 35,476, 35,477, 35,478, 35,482

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.61 %	Mins	Mins
Minimum	12.51 %	Mins	Mins
Average	12.54 %	45+ Mins	30 Mins
			Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound XX/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent

Percentage Remix to Whole 10

TEMPERATURES °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	TIME Days	Hours
		Load Forced Air Dry at ambient temperature		
Ambient	140	Increase temperature 5°F per hour		
140	140	Hold at temperature		36

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION

Constituent	Percent Formula	Percent Tolerance	Percent Measured
Nitrocellulose	28.00	±1.30	28.77
Nitroglycerin	22.50	±1.00	22.26
Nitroguanidine	47.70	±1.00	47.15
Ethyl Centralite	1.50	±0.10	1.48
Cryolite	0.30	±0.10	0.34
TOTAL	100.00		100.00
Total Volatiles	0.50	Max.	0.19
Graphite Glaze	0.2	Max.	0.16

STABILITY AND PHYSICAL TESTS

	Formula	Actual
Heat Tests SP,120°C	No CC 40'	CC 50'
No Fumes		NF 60'
Form of Propellant		Cyld.
No. of Perforations		7

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-69315	+90	96.08	100.00
Standard	E-32	+90	100.00%	100.00%

Remarks: FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1.1 IN A NOMINAL SIZE 200CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec	Actual
Length (L)		0.395	0.3977	6.25 Max.	2.40
Diameter (D)		0.192	0.1709	6.25 Max.	1.83
Perf Dia. (d)		0.020	0.0153		
Web					
Inner		0.0355	0.0294		
Outer		0.0305	0.0340		
Average	0.033 Nom.	0.0330	0.0317		
Web Difference/Std. Dev. in % of Web Average	15 Max.		14.7		
L/D	2.10 to 2.50		2.33		
D/d	5.0 to 15		11.2		

DATES

Packed	2/1/75
Sampled	2/1/75
Test Finished	2/12/75
Offered	2/18/75
Description Sheets Forwarded	2-21-75

Type of Packing Container: Fiber Drums per MIL-STD-652C, with Notice 1.

Remarks: This lot meets all requirements of the applicable specifications.

Contractor's Representative: J. K. MULLER — OH MULLER [signature]

Government Quality Assurance Representative [signature]

Figure 8. Propellant Description Sheet - RAD-69315

However, the simulations for the M-30 composition lot were more promising. Purposefully the smallest readily available web for an M-30 lot was chosen; this was lot RAD 69315 which was produced for the M724E1 round to be fired from the 105mm, M68, tank gun. The propellant description sheet is given in Figure 8. The average web was 0.805 mm (0.0317 inch) with a seven-perforation cylindrical geometry. The initial propellant gas production, pressure, and projectile acceleration were less than those of the IMR 4996 because the initial total surface area of the charge was less than that of the IMR propellant. The desired velocity level of 1524 m/s was expected at a maximum pressure of about 400 MPa (58,000 psi). The simulation predicted a maximum acceleration of 0.747×10^6 m/s^2, with an average accleration of about 0.312×10^6 m/s^2. This performance was to be expected from the progressive burning resulting from the multi-perforated geometry instead of from a deterrent coating on a single-perforated geometry. In addition, the M-30 propellant is a more energetic composition. As an ignition aid for the M-30 propellant charge, 1.3 - 2.0 grams of Class V black powder was selected. Plots of the M-30 simulation are shown in Figures 9, 10, and 11: pressure vs time, pressure vs travel, and velocity-travel-acceleration vs time. Further calculations by Terminal Ballistics Division personnel indicated that the penetrators should withstand these launch conditions.

A quantity of this M-30 composition, lot RAD-69315, was obtained and tested. The results were encouraging, but not completely successful. The desired velocity was not attained; however, for similiar charge weights, the M-30 propellant showed a higher velocity/pressure ratio than the IMR 4996 or the HC-25-FS. The calculated ballistic efficiencies of the M-30 tests were much lower than that of the simulation, 0.17 as opposed to 0.23. In order to improve the ignition and combustion of the charge in the real system and thereby obtain a higher efficiency, a reduction in the web size of the propellant was required. Three small lots of experimental multi-perforated M-30 propellant were readily available. They had been manufactured for a reduced scale gun and had webs respectively of 0.33 mm (0.0128 in.), 0.37 mm (0.0147 in.), and 0.40 mm (0.0156 in.)[2]. If any of these lots were used alone as the substitute charge, it would result in extremely high pressure and acceleration. However, if one were mixed in suitable proportions with the larger web M-30, the resulting charge should result in improved ignition, combustion, and ballistic efficiency. Mr. Grollman and Mr. Baer[3] of the Ballistic Research Laboratory recommended that a single propellant with a single web size be used for efficient burning. This type of propellant was not available, however, the desired results could be achieved but with less efficiency with propellant mixtures having different web sizes.

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[2] *G. Samos, B. Grollman, and J. Schmidt, "Initial Firing Test Results of the 35mm Scaled Model of the 105mm M68 Tank Gun", Ballistic Research Laboratory Memorandum Report No. ARBRL-MR-02804, January 1978 (ADA051050).*

[3] *B. Grollman and P. Baer, "Theoretical Studies of the Use of Multi-Propellants in High Velocity Guns", Ballistic Research Laboratories Report No. 1411, August 1968 (AD839855).*

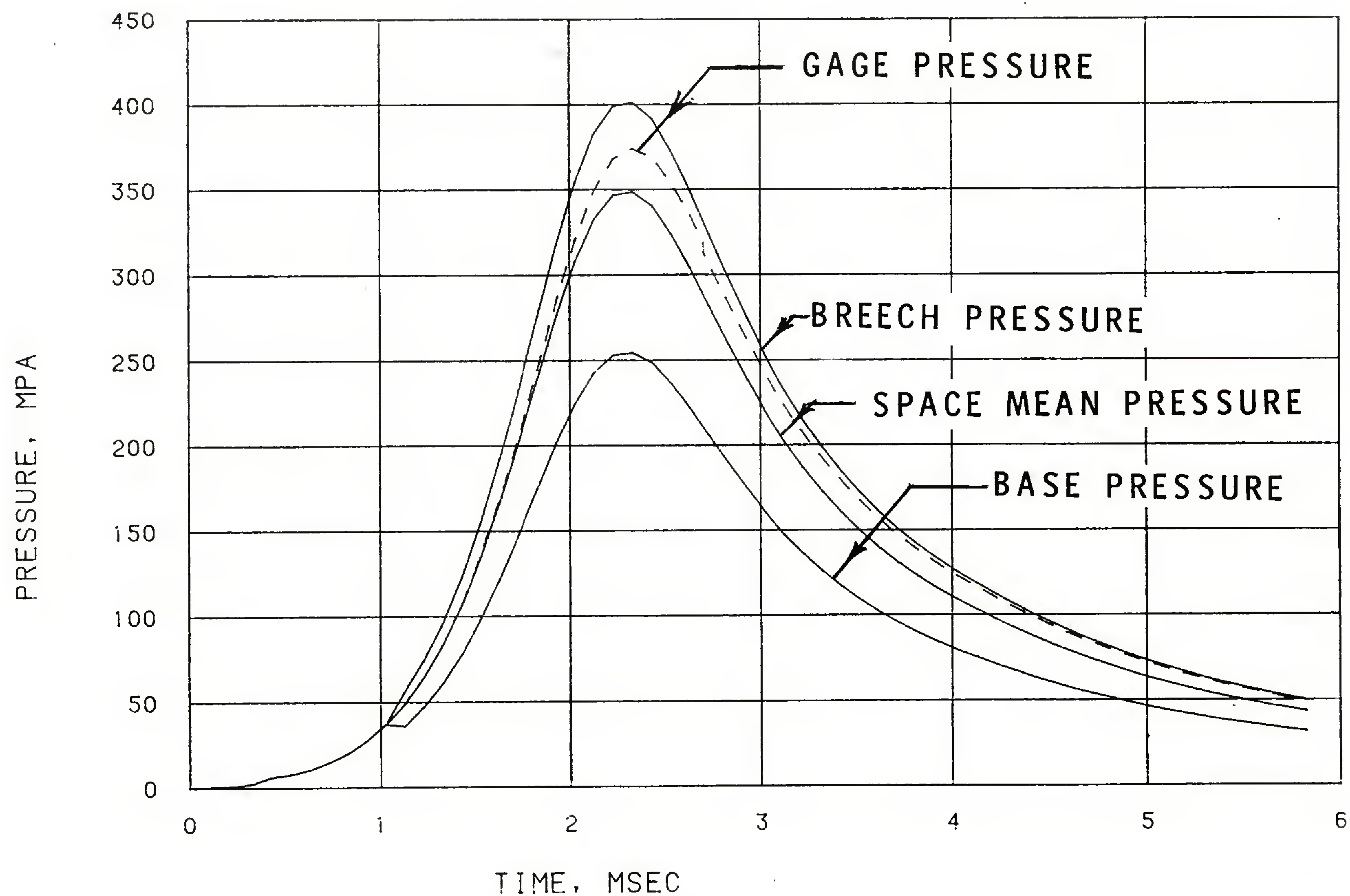

Figure 9. Pressure vs Time - M30

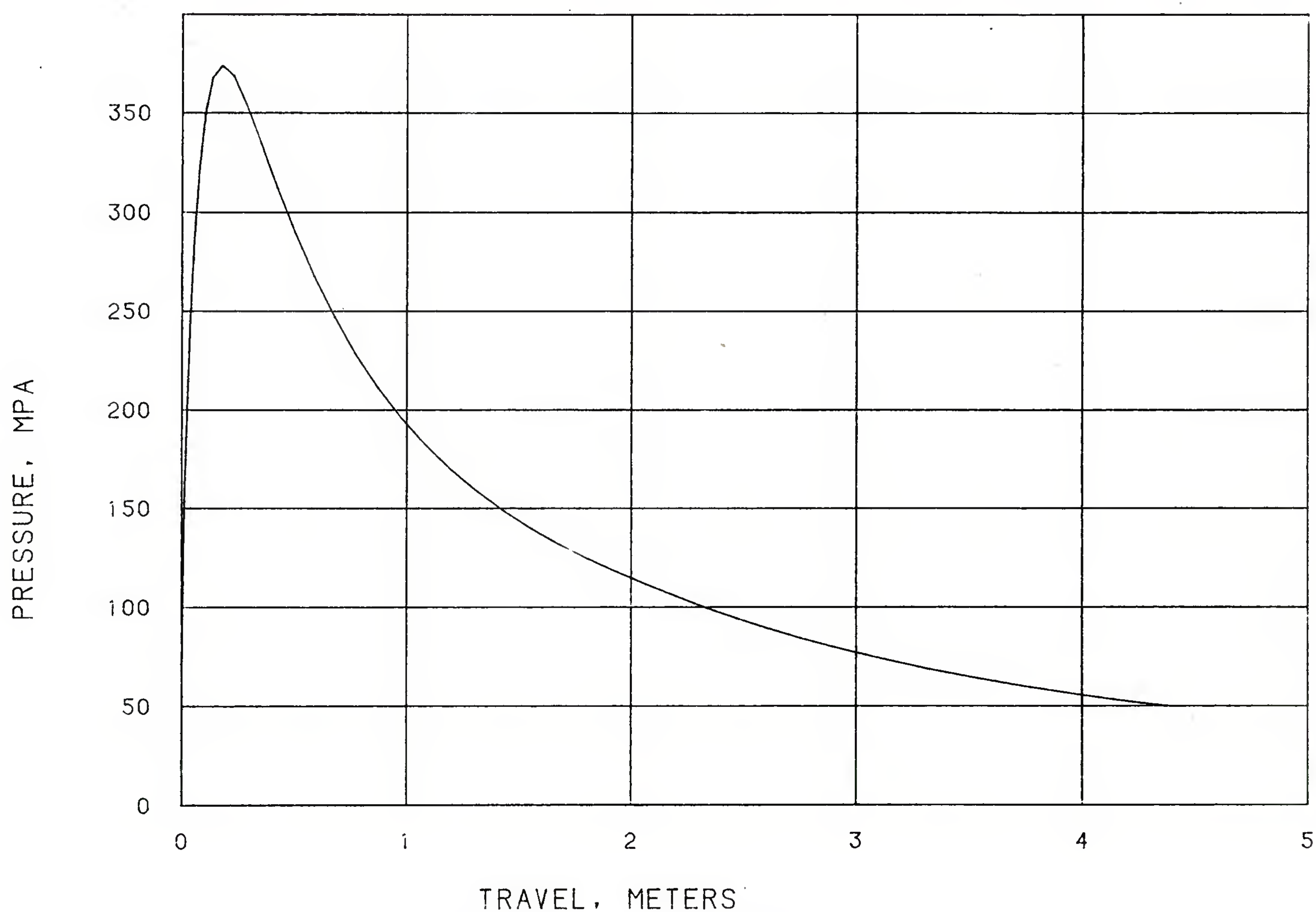

Figure 10. Pressure vs Travel - M30

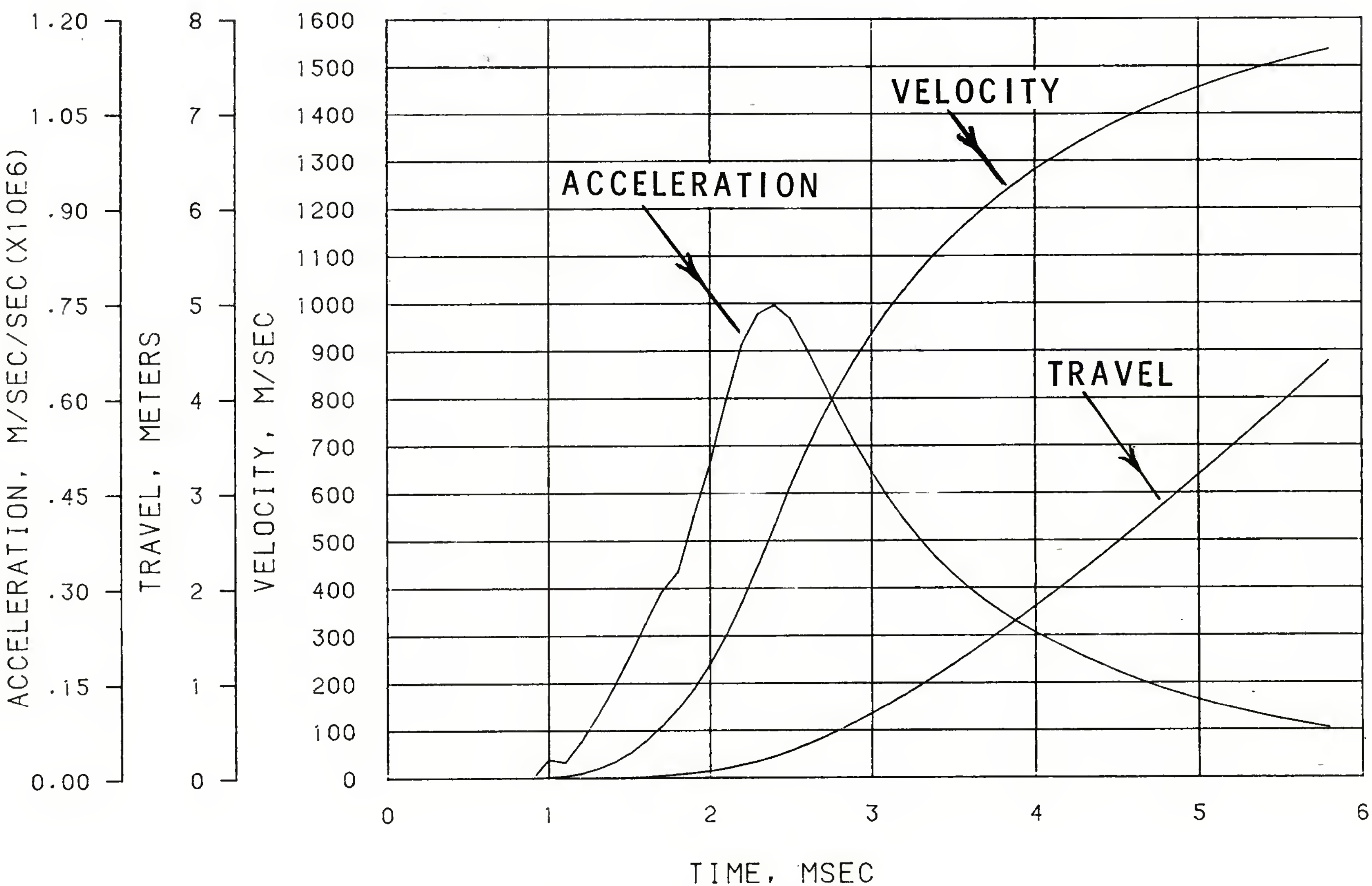

Figure 11. Velocity-Travel-Acceleration vs Time - M30

A quantity of the 0.37-mm (0.0147-in.) web M-30 propellant, lot RAD-E-30, was obtained for this purpose. The propellant description sheet is attached as Figure 12.

A charge establishment firing series was conducted with increasing charges of increasing ratios of small to large web propellants. This resulted in a charge establishment of M-30 composition with multi-perforated granulation which gives the desired velocity levels without penetrator damage.

A charge weight of 129.7 grams (0.286 lb) with the following proportions produced a muzzle velocity of 1525 m/s (5003 ft/s) with a maximum copper-crusher gage pressure of 433 MPa (62,800 psi).

	Percent
M-30, Lot RAD-E-30, 0.37-mm web	38.
M-30, Lot RAD-E-69315, 0.81-mm web	61.
Black Powder Class V	1.

Figures 13 and 14 are radiographs of the launchings resulting from using propellant IMR 4996 and the improved propellant charge, respectively. The latter charge does no damage to the penetrator. Additional test firings of similar charges have produced satisfactory results.

4.3 Summary of Results

a. Sabot modification alone was incapable of protecting the penetrator from plastic deformation during launch.

b. The search for a propelling charge to solve this problem was successful.

c. The third step in the APPROACH, a modified launcher, was not undertaken because other gun systems were not readily available. The acquisition time would have severely delayed ARAP in its contractual effort. However, the 26-mm smooth bore barrel and 37-mm breech gun system at BRL's Terminal Ballistics Division regularly launches these DU penetrators successfully at 1524 m/s. Thus, had time permitted, the launch problem could have been solved by installation of such a gun system.

d. Table 2 gives the sequence of events and the test results. Firings 1 thru 26 failed to provide a solution, that is, the penetrator was: (1) not deformed but too low a muzzle velocity, (2) slightly deformed at higher muzzle velocities, or (3) grossly deformed at muzzle velocities approaching 1524 m/s. Figure 13 shows a grossly deformed and fractured penetrator launched at a velocity of 1534 m/s (5032 ft/s). Figure 14 shows an undeformed penetrator launched at a velocity of 1530 m/s (5020 ft/s). Firings 27 thru 31 are successful launches.

e. The 20 firings for record for ARAP were all successful launches.

PROPELLANT DESCRIPTION SHEET

Lot No. RAD-E-30 of 19 73 Composition No. M30, MP f/105mm M68, 35mm Scaled

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 269 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR Letter SMURO-IE dated 2 March 1973

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
A-35,332	Maximum ___ %	___ Mins.	___ Mins.
	Minimum ___ %	___ Mins.	___ Mins.
	Average 12.54 %	45+ Mins.	30+ Mins.
			Explosion ___ Mins.

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent

Percentage Remix to Whole 10

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		Load Forced Air Dry at Ambient Temperature		
Ambient	140	Increase Temperature 5°F Per Hour		
140	140	Hold at Temperature		24

TESTS OF FINISHED PROPELLANT

Propellant Composition Constituent	Percent Formula *	Percent Tolerance *	Percent Measured	Stability and Physical Tests	Formula *	Actual
Nitrocellulose	28.00	±1.30	28.48	Heat Test, SP, 120°C	No CC 40'	60'
Nitroglycerin	22.50	±1.00	22.81	No Fumes		60'
Nitroguanidine	47.70	±1.00	46.90	Form of Propellant		Cyld.
Ethyl Centralite	1.50	±0.10	1.53	No. of Perforations		7
Cryolite	0.30	±0.10	0.28			
TOTAL			100.00			
Total Volatiles	0.50	Max.	0.27			
Graphite Glaze	0.2	Max.	0.08			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test				
Standard			100.00%	100.00%
Remarks				

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions: Spec*	Actual
Length (L)		0.2070	0.2065	6.25Max.	1.74
Diameter (D)		0.0990	0.0943	6.25Max.	2.60
Perf Dia (d)		0.0160	0.0123		
Web Inner		0.0205	0.0096		
Web Outer		0.0085	0.0198		
Web Avg.		0.0142	0.0147		
Nom.Avg.Web	0.0152				
Web Difference/Std Dev in % of Web Average	15 Max.*		70		
L/D	2.10 to 2.50*		2.19		
D/d	5.0 to 15*		7.6		

Dates	
Packed	10/5/73
Sampled	10/5/73
Test Finished	10/17/73
Offered	10/18/73
Description Sheets Forwarded	10/25/73

Type of Packing Container Fiber Drums per MIL-STD-652B.

Remarks imits from MIL-STD-652B w/EO PA-56070-2 and EO PA-57189-2 shown for information only. Propellant produced on a best effort basis in accordance with referenced COR letter.

20

Contractor's Representative H. E. BISHOP

Government Quality Assurance Representative JAMES [illegible] BLAND

Figure 12. Propellant Description Sheet - RAD-E-30

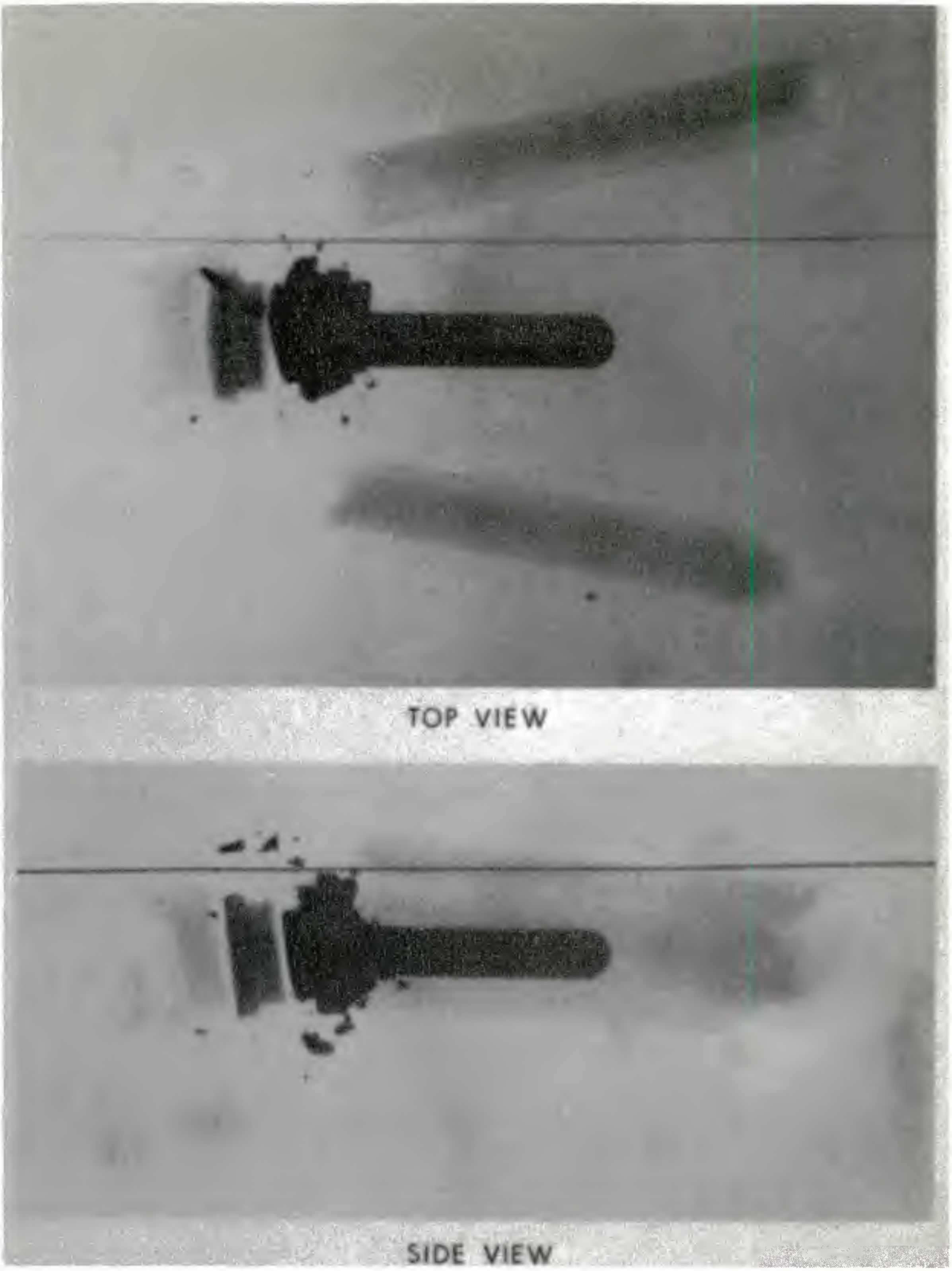

Figure 13. Radiograph Of A Penetrator Launched At 1534 m/s using IMR 4996 Propellant.

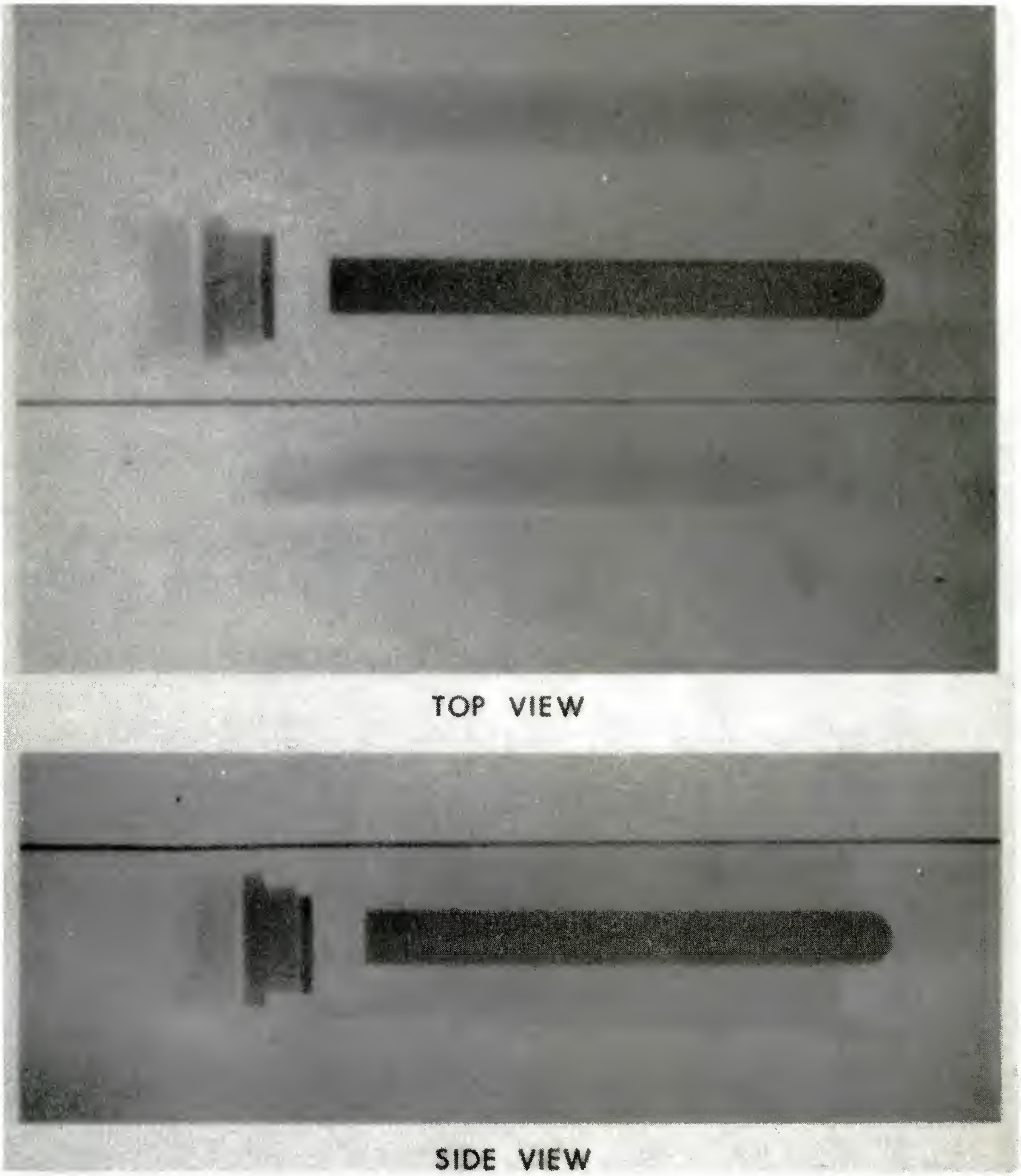

Figure 14. Radiograph Of A Penetrator Launched At 1530 m/s using Improved Propellant Charge

Table 2. Sequence of Events and Test Results

Shot Number	Launch Weight g	Propellant		Chamber		Muzzle Velocity m/s	Sabot Type	Remarks
		Type	Weight g	Length cm	Pressure MPA			
1	99.5	IMR 4996	74.5	17.78	142.0	-	Original	WA Rod - ND
2	99.7	IMR 4996	81.0	17.78	232.4	-	Original	WA Rod-VSDAE
3	99.8	IMR 4996	90.7	17.78	399.2	1386	Original	WA Rod - ND
4	99.6	IMR 4996	97.2	17.78	488.2	-	Original	WA Rod - ND
5	99.2	IMR 4996	106.9	20.32	454.4	1534	Original	DU Rod - RF
6	99.4	IMR 4996	113.4	20.32	524.7	1366	Original	DU Rod - RF
7	99.8	IMR 4996	100.4	20.32	439.9	1443	Original	DU Rod - RF
8	99.5	HC-25-FS	107.6	20.32	456.4	1496	Original	DU Rod - RF
9	99.6	HC-25-FS	90.7	20.32	180.6	1224	Original	DU Rod - ND
10	99.8	HC-25 FS	103.7	22.86	-	1264	Original	DU Rod - ND
11	99.4	HC-25-FS	116.6	22.86	279.2	1408	Original	DU Rod - ND
12	100.7	HC-25-FS	123.1	22.86	367.5	1450	Original	DU Rod - ND
13	108.1	HC-25-FS	132.8	22.86	482.7	1479	Original 2 plastic discs	DU Rod - VSDAE

D - Deformation ND - No Deformation
VSDAE - Very Slight Deformation - AFT End
R.F. - Rod Fractured

Table 2. Sequence of Events and Test Results (Cont'd)

Shot Number	Launch Weight g	Propellant Type	Propellant Weight g	Chamber Length cm	Chamber Pressure MPA	Muzzle Velocity m/s	Sabot Type	Remarks
14	109.1	HC-25-FS	132.8	22.86	483.3	1470	Original + 2 steel discs	DU Rod - VSDAE
15	109.2	HC-25-FS	139.3	22.86	-	1390	Long hat 2 steel discs	RF, DU Rod
16	108.2	Blk pwdr 1.3g,lot CIL-7-5, MP 30, .805mm web lot RAD 69315	110.2	22.86	180.0	1205	Long hat + 2 steel discs	ND, DU Rod
17	107.8	same as 16, blk pwdr wgt held constant	114.0	22,86	174.4	1259	Long hat 2 steel discs	Du Rod - ND
18	107.9	Same as 16, blk pwdr wgt held constant	119.2	22.86	242.7	1308	Long hat 2 steel discs	ND, DU Rod
19	107.5	Same as 16, blk pwdr wgt held constant	117.9	22.86	192.4	1289	Long hat 2 steel discs	ND, DU Rod
20	107.8	1.94g blk pwdr, same M30 wgt as #19	118.7	22.86	182.0	1303	Long hat 2 steel discs	ND, DU Rod

Table 2. Sequence of Events and Test Results (Cont'd)

Shot Number	Launch Weight g	Propellant Type	Propellant Weight g	Chamber Length cm	Chamber Pressure MPA	Muzzle Velocity m/s	Sabot Type	Remarks
21	107.9	64.8g IMR 4996 58.3g M30	123.1	22.86	428.9	1484	Long Hat 2 steel discs	RF, DU Rod
22	107.9	1.3g Blk Pwdr 102.1g M30, .805mm Web, 11.34g M30, .386mm Web	114.7	22.86	153.1	1220	Long Hat 2 steel discs	ND, DU Rod
23	108.0	1.3g Blk Pwdr 105g M30, .805mm web 11.66g M30, .386mm	117.9	22.86	217.9	1217	Long Hat 2 steel discs	ND, DU Rod
24	107.8	1.3g Blk Pwdr 103.7g M30, .806mm web 14.6g M30 .386mm web	119.6	22.86	227.5	1366	Long Hat 2 steel discs	ND, DU Rod
25	107.0	1.3g Blk Pwdr 93.3g M30 .806mm web 23.3g M30	117.9	22.86	237.2	1370	Long Hat 2 steel discs	ND, DU Rod
26	108.2	1.3g Blk Pwdr 86.2g M30 .806mm 36.9g M30 .386mm web	124.4	22.86	337.9	1470	Long Hat 2 steel discs	ND, DU Rod

Table 2. Sequence of Events and Test Results (Cont'd)

Shot Number	Launch Weight g	Propellant Type	Propellant Weight g	Chamber Length cm	Chamber Pressure MPA	Muzzle Velocity m/s	Sabot Type	Remarks
27	107.6	1.3g Blk Pwdr 78.4g M30, .806mm web 49.2g M30, .286mm web	128.9	22.86	444.7	1527	Long Hat 2 steel discs	ND
28	107.6	1.3g Blk Pwdr 82.9g M30, .806mm web 49.3g M30, .386mm web	133.5	22.86	474.4	1559	Long Hat 2 steel discs	ND
29	108.1	1.3g Blk Pwdr 78.4g M30, .806mm web, 49.2g M30, .386mm web	128.9	22.86	404.0	1509	Long Hat 2 steel discs	ND
30	107.7	1.3g Blk Pwdr 79.1g M30, .806mm web, 49.2g M30, .386mm web	129.6	22.86	443.3	1525	Long Hat 2 steel discs	ND
31	100.8	Same as 30	129.6	22.86	433.0	1530	Original	ND

5. RECOMMENDATIONS

1. A single propellant with a uniform grain size and web should be designed and produced for future firing tests of an extended nature.

2. The propellant search undertaken here should be extended to the TBD 26-mm barrel/37-mm breech gun system to provide even higher launch velocities at tolerable pressure levels.

3. The Test and Instrumentation Division, Technical Support Directorate, ARRADCOM range with its new capability should be employed by BRL to reduce backlogged firing programs.

REFERENCES

1. C. Grabarek and L. Herr, "X-Ray Multi-Flash System for Measurement of Projectile Performance at the Target", Ballistic Research Laboratories Technical Note No. 1634, September 1966 (AD No. 807619).

2. T. R. Trafton, "An Improved Interior Ballistic Model for Small Arms Using Deterred Propellants", Ballistic Research Laboratory Report No. 1624, November 1972 (AD No. 907962L).

3. G. Samos, B. Grollman, and J. Schmidt, "Initial Firing Test Results of the 35-mm Scaled Model of the 105-mm M68 Tank Gun", Ballistic Research Laboratory Memorandum Report No. ARBRL-MR-02804, January 1978 (AD No. A051050).

4. B. Grollman and P. Baer, "Theoretical Studies of the use of Multi-Propellants in High Velocity Guns", Ballistic Research Laboroatory Report No. 1411, August 1968 (AD No. 839855).

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6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ____________________

Telephone Number: ____________________

Organization Address: ____________________

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